Corps/USGS/NOAA/BuRec Climate Change Workshop

Water Resources Management : Adapting to Uncertainty

Eugene Z. Stakhiv
Institute for Water Resources
US Army Corps of Engineers

Hurricanes & Global Warming?

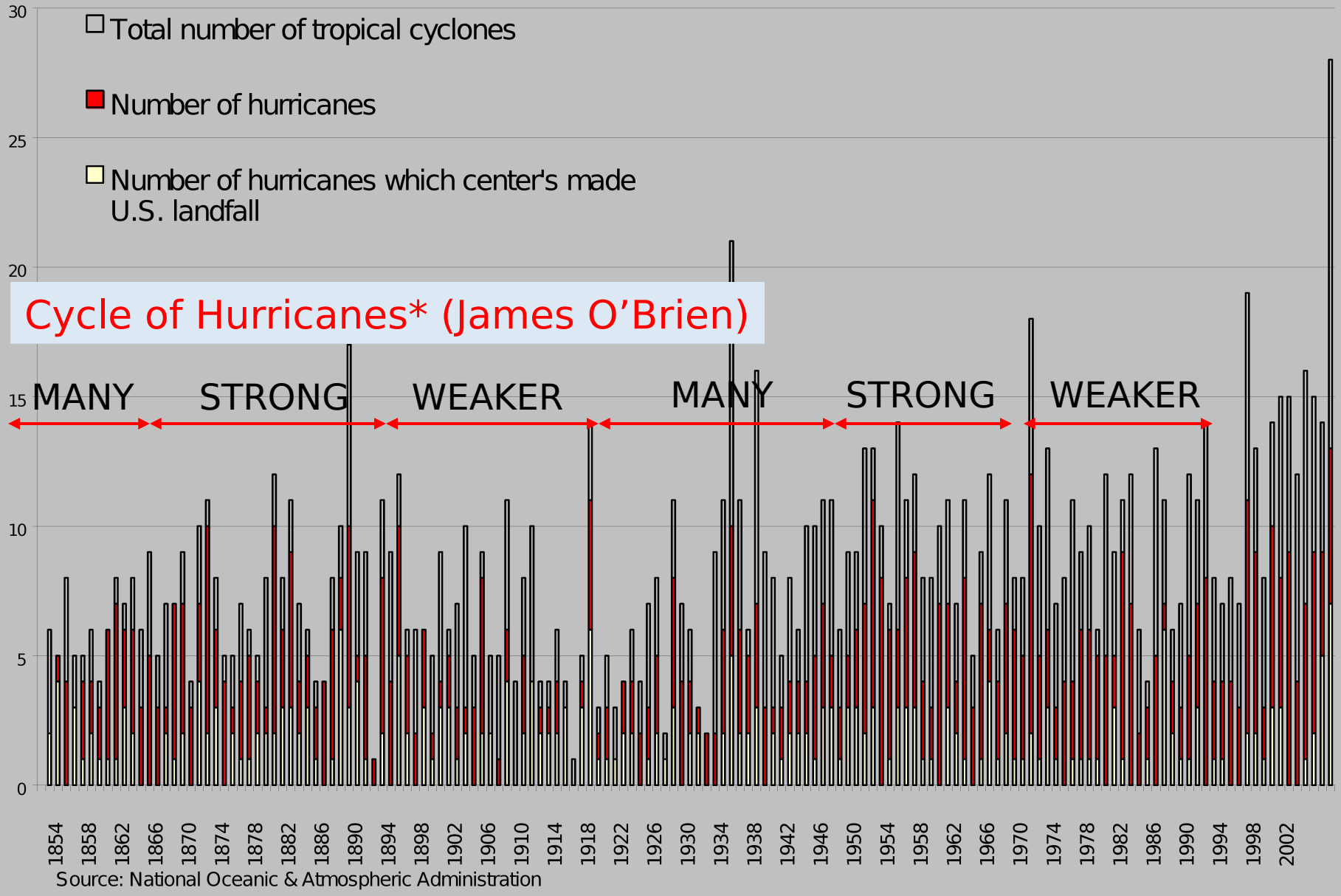
- 2004, 2005 Atlantic hurricane seasons broke many records
- 2006 predicted to have 15 named storms; 10 hurricane strength; 4-5 major making landfall in US

  2006 A BUST !!! Not much happened (FEMA, Corps and other agencies spent $ tens millions preparing, anticipating)
- **Debate among US meteorologists:**

A. 25-40 yr cycle ? (e.g. Landsea & Gray) or

B. part of global warming cycle ? (e.g. Emmanuel)

Herein lies the problem for water engineers- how to translate vague climate scenarios, scientific disputes and flawed predictions into design criteria for reliable structures and response systems?


Total number of tropical cyclones
Number of hurricanes
Number of hurricanes which center's made U.S. landfall
Cycle of Hurricanes* (James O'Brien)
MANY
STRONG
WEAKER
MANY
STRONG
WEAKER
30
25
20
15
10
5
0
1854 1858 1862 1866 1870 1874 1878 1882 1886 1890 1894 1898 1902 1906 1910 1914 1918 1922 1926 1930 1934 1938 1942 1946 1950 1954 1958 1962 1966 1970 1974 1978 1982 1986 1990 1994 1998 2002
Source: National Oceanic & Atmospheric Administration

Note: Prior to 1970, tropical cyclones were not monitored by satellites; meaning that those cyclones that did not hit the land of the United States were not systematically recorded.

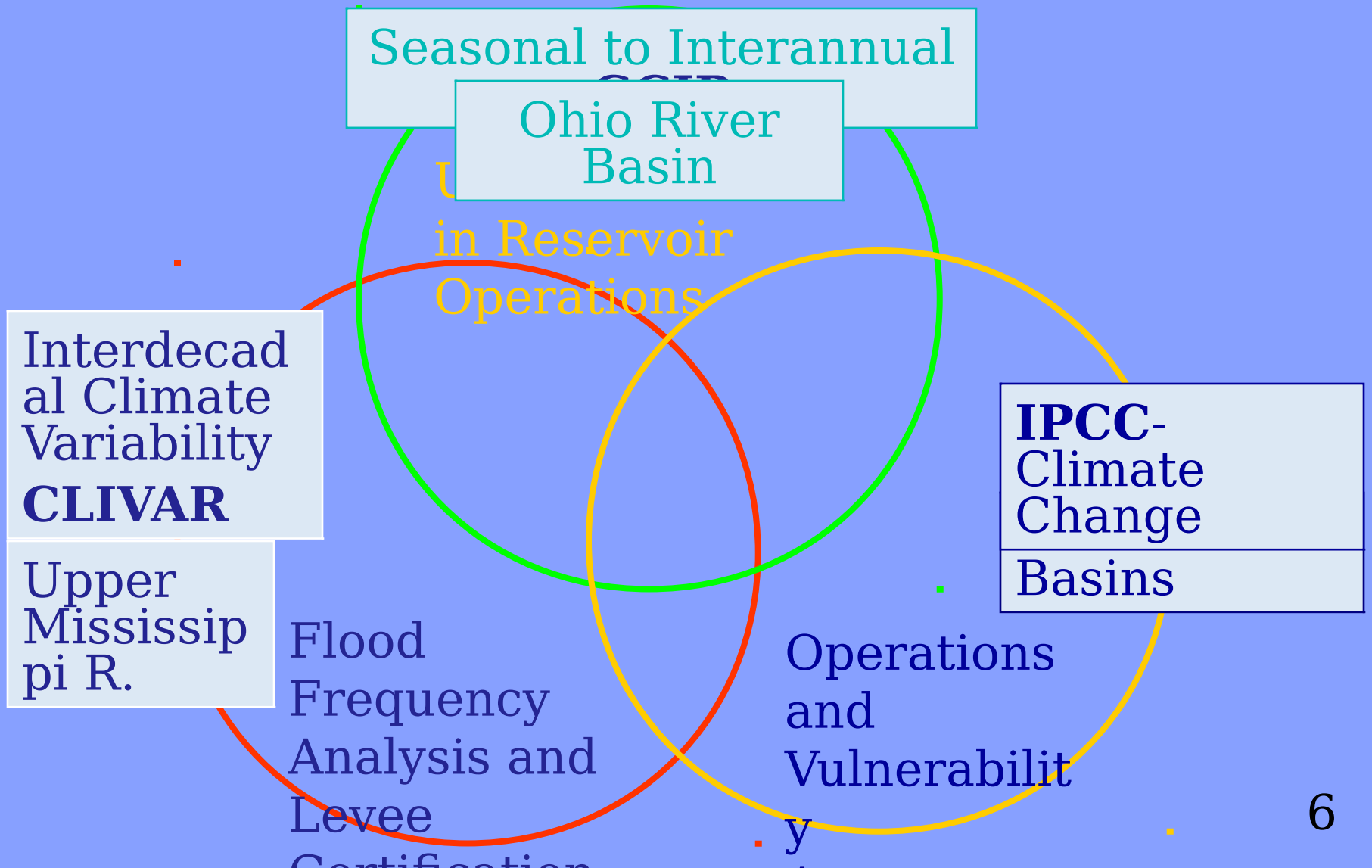
Recent Studies

- Hundreds of studies, thousands of papers
- IPCC I, II, III (IV in press)
- US National Climate Assessment
- International Joint Commission
  -Lake Ontario-St. Lawrence Study
  -Upper Lakes Study
- Corps studies
  -Upper Miss R. Flow Freq study
  -Ohio R. Climate Forecasting Study
  -8 River Basin climate assessments under various IPCC climate scenarios/ GCM transient models

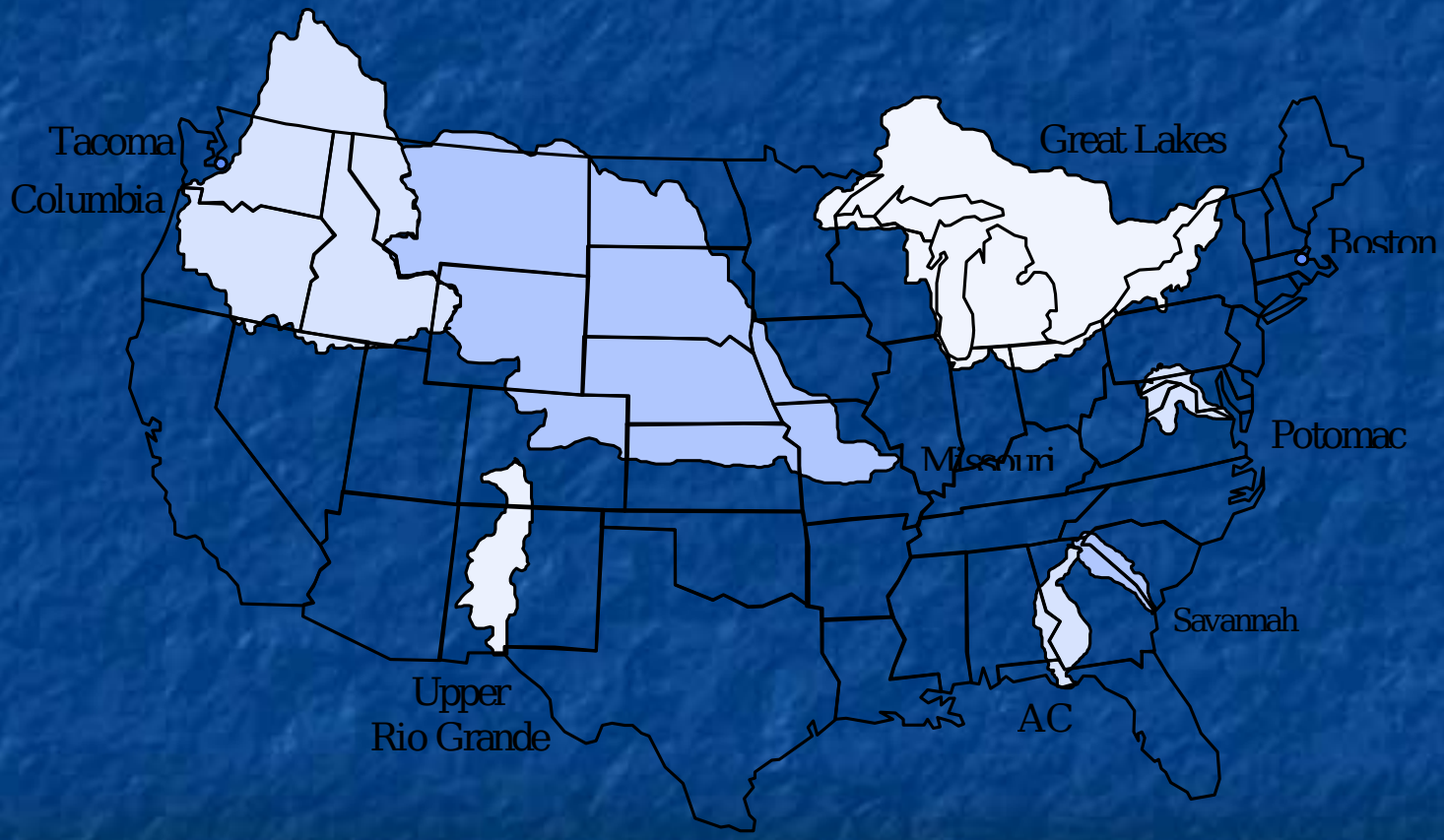
Types of Climate Change Studies

- Broad IPCC GCM-based impact studies (many GCMs, scenarios; large uncertainties; downscaling problems
- Stochastic/synthetic hydrology – watershed based runoff models – based on historic record to test robustness/resiliency of operating system
- ‘experiments’ extending GCM impacts to derive flood and drought frequencies
- USGS-type statistical analysis of stream flow and precip intensity-duration-area curves of NWS
- Probabilistic forecasts of historic stream flows – ‘spaghetti diagrams’

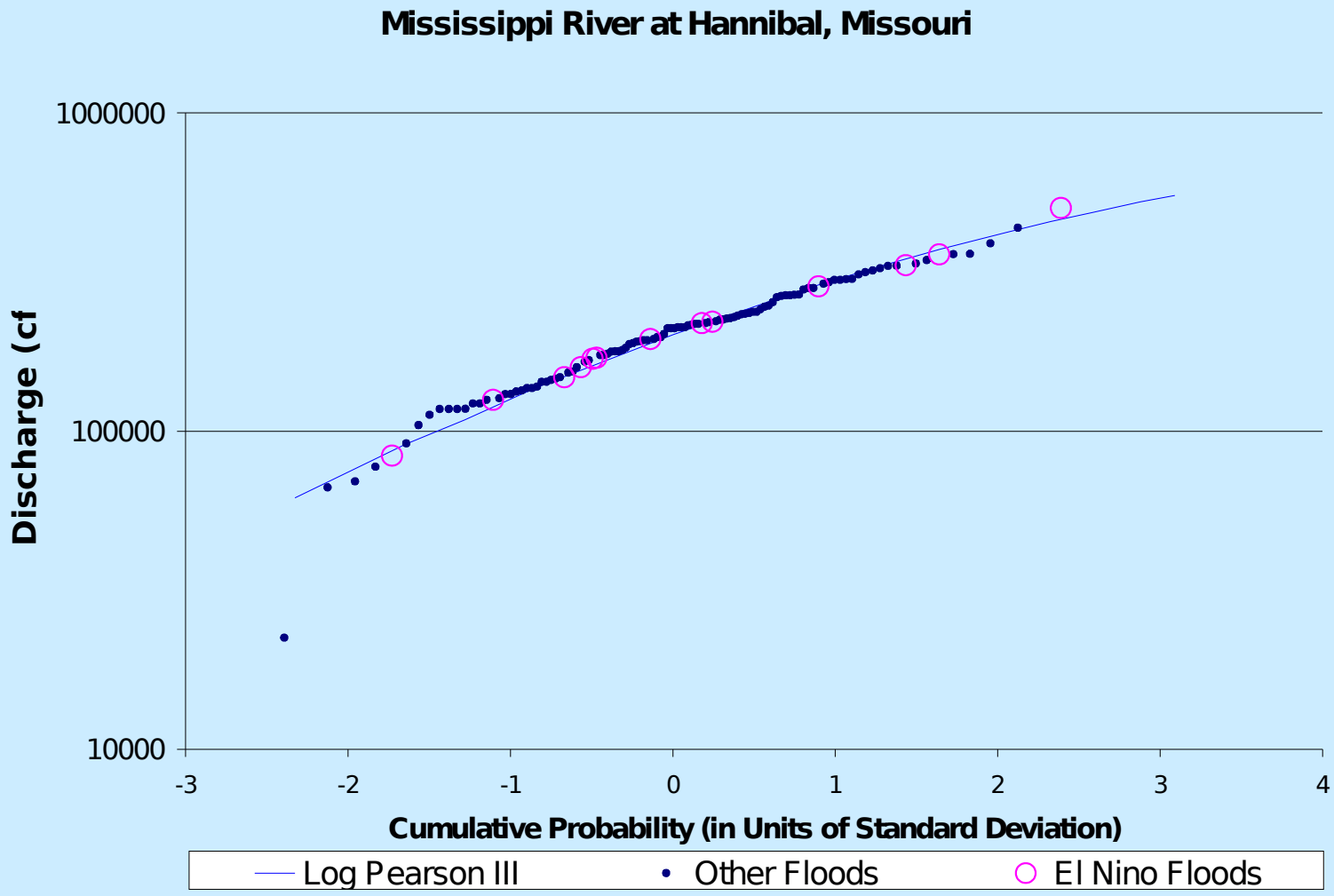
Climate Time Scales and Water Resources Management Uncertainties



Corps IPCC Climate Impact Assessment



ENSO Floods


Mississippi River at Hannibal, Missouri
1000000
100000
10000
Discharge (cf
-3
-2
-1
0
1
2
3
4
Cumulative Probability (in Units of Standard Deviation)
Log Pearson III
Other Floods
El Nino Floods

IPCC Lexicon of Adaptation

- **Precautionary Principle** (Anticipatory Adaptation-prevent uncertain damages)
- **Adaptation/Adaptive management**

  "Proactive '*No Regrets*' Adaptation." (strategic planning, justifiable under current criteria; efficient, cost-effective; serves multiple purposes; adaptable to changing circumstances, technically feasible, etc.)

  "Autonomous Adaptation" (ad hoc cumulative, tactical incremental adjustments to demands, needs, demographic patterns and technology)

Factors to consider

- The history of water management is one of continuous adaptation to uncertainties; water engineering is about learning from mistakes (Katrina; Miss. R Floods 1927, 1973, 1993, droughts)
- Various rules, procedures, design safety factors have evolved to accommodate R&U
- There is a significant turnover in water management infrastructure: ~ every 30-50 yrs capacity can be upgraded/ reconfigured to adapt - rehabilitation
- The discount rate, BCA procedures, IRR vs max net NED benefits is more relevant than climate uncertainty in determining modes of adaptation.
- 'Optimal' solutions are often 'brittle' (not robust, nor resilient to unexpected circumstances).

Functions/Elements of Water Resources Management
Conventional Mechanisms for Adapting to Uncertainties

- Planning **new investments**, or for capacity expansion (reservoirs, irrigation systems, levees)
- **Operation & regulation** of existing systems: accommodating new uses or conditions (e.g. ecology, climate change, population)
- Maintenance and **major rehabilitation** of existing systems (e.g. dam safety, levees, etc.)
- Modifications in **processes and demands** (water conservation, pricing, regulation, legal)
- Introduce new **efficient technologies** (desalting, biotechnology, drip irrigation, reuse, recycling, solar, etc.)

Planning/Design Perspectives

- **Conventional BCA** – decision rule: select design level that maximizes net benefits (requires frequency of events) – discount rate ?
- **Standards-based approach**: pre-select design level (e.g. PMP, PMF, PMH, 100-yr) arbitrary levels or physically- based
- **Decision Rules:** min-max; min risk-cost; risk-cost effectiveness; NOAEL, etc.
- Most **water mgmt is a combination** of the three- all require better hydrologic data, excedance frequencies, PDF's (e.g dam design)
- What is a safe/reliable/affordable level of protection? How to determine?; who decides?

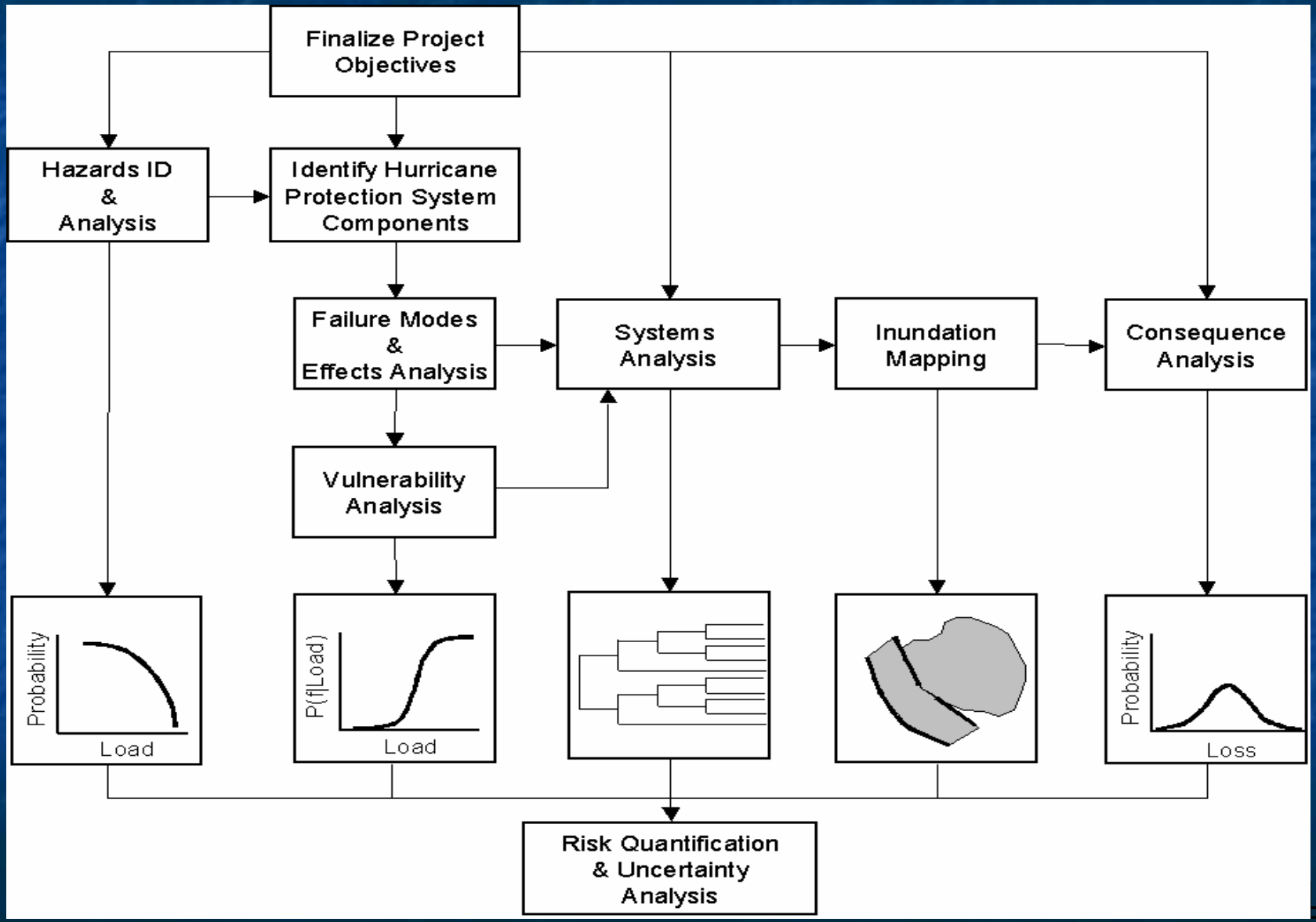
Corps Focus is on ***Climate Variability*** – expanded use of traditional methods for risk, reliability and uncertainty analysis

All design, operations, rehabilitation require 'planning' Corps works on combined basis of standards & risk

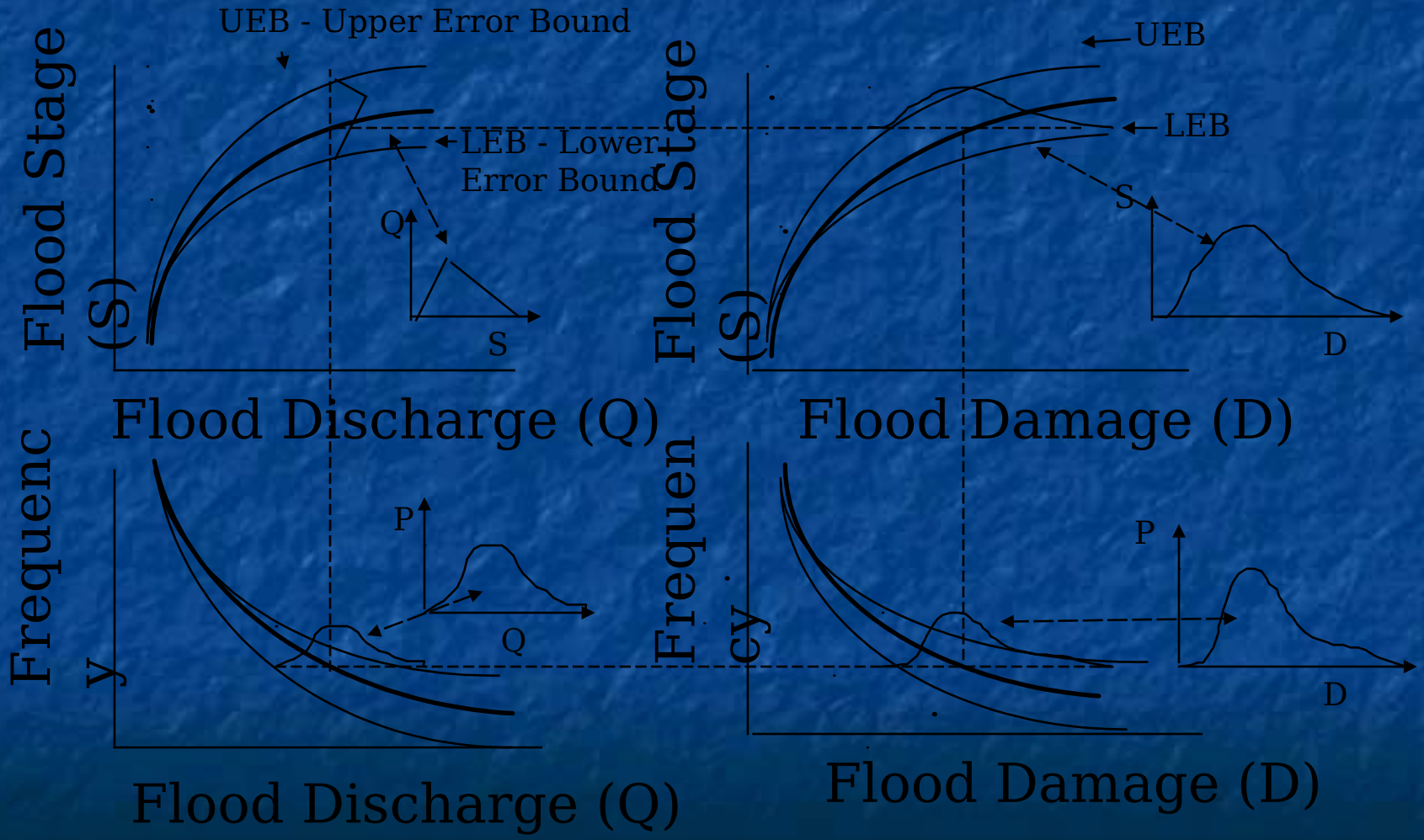
- Dam safety (convert PMP/PMF to risk-based designs)
- Levee design criteria (SPF to risk-based designs)
- Shore erosion, coastal protection (PMH)
- Reservoir operating criteria, improved forecasting
- Reservoir/system water allocation changes
- Delineation of 100-year floodplains/NFIP
- Drought & Flood Contingency Mgmt (reservoir, urban)
- Emergency Operations/Advanced Measures (seasonally anticipated snowmelt flooding, hurricanes)

Need new methods for flood/drought frequency analysis under non-stationary climate, with trends

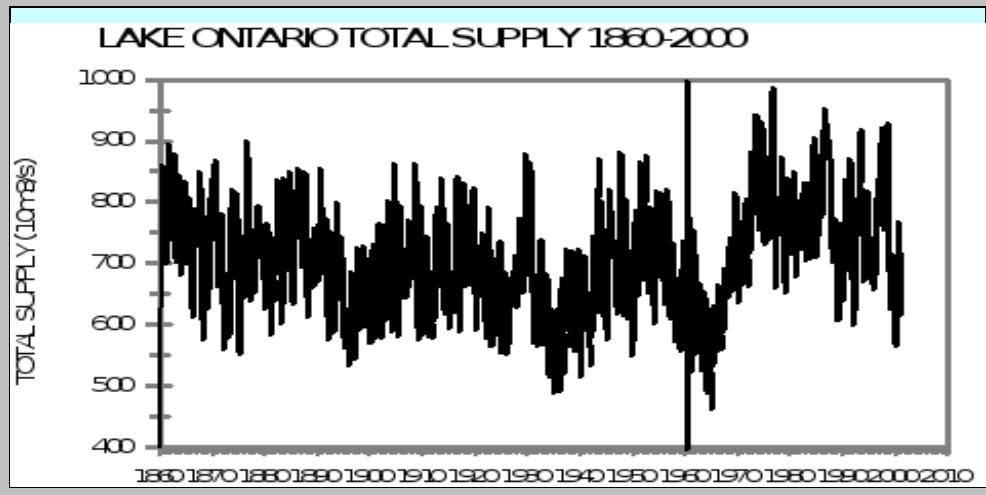
Risk and Reliability Methodology



Uncertainty and Flood Damage Calculation



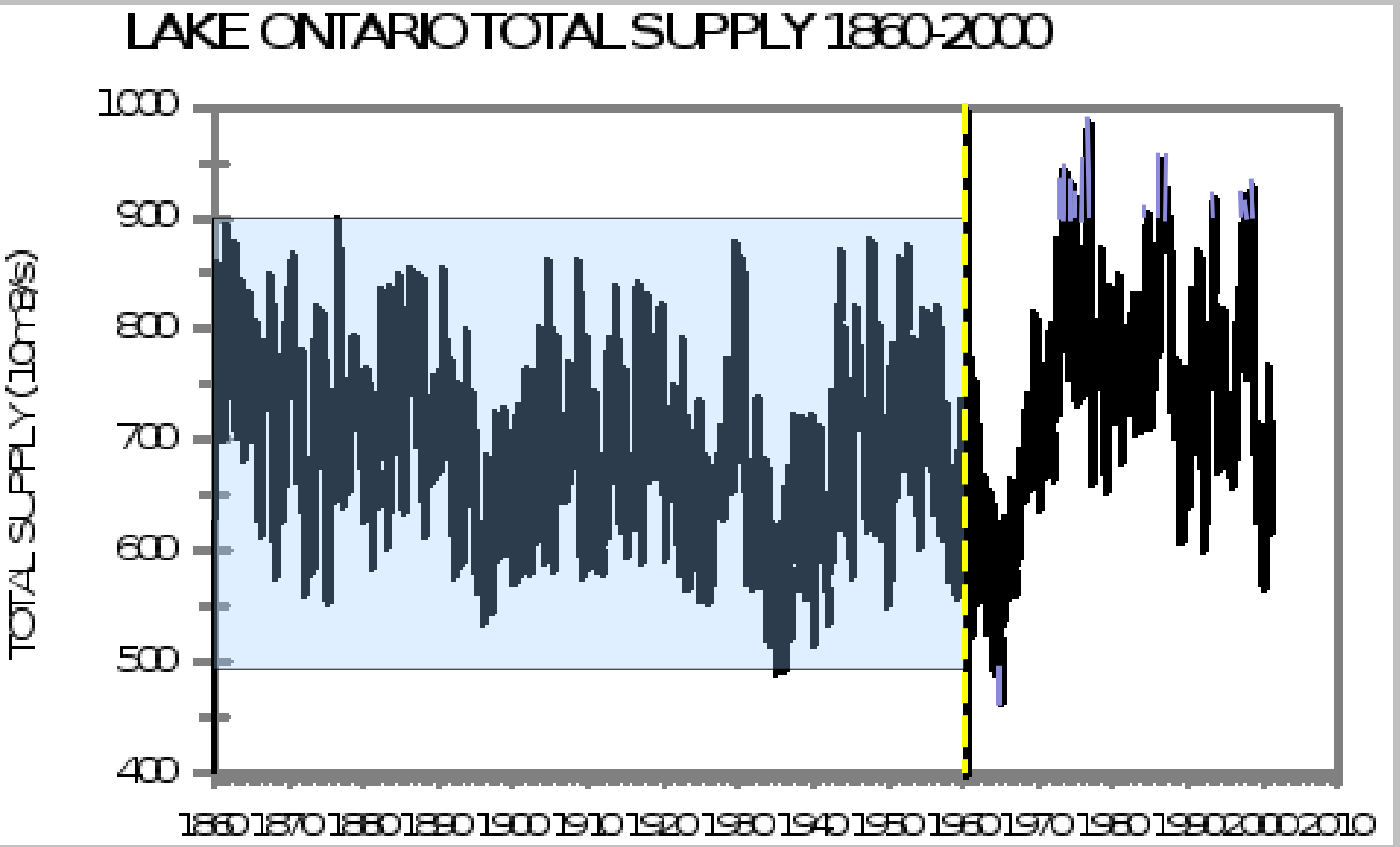
Changing Great Lakes Water Levels



- **Water Level Shifts**
  - Highs - 70s-90's
  - Lows - 60's, 1998-2001
- **Impacts**
  - High Levels
    - Erosion – Flooding
  - Low Levels
    - Hydropower - Navigation - Recreational Boating - Environment
- **Actions - Review of IJC Order**
  - $20 M St. Lawrence-Ontario Study (completed)
  - $15 M Upper Lakes Study (2006-2011)
- **Unknown - Climate Change**

Ongoing Adaptation Initiatives Great Lakes/IJC

- Great Lakes Water Quality Agreement
- Lakewide Management Plans (LaMPs)
- Remedial Action Plans (RAPs)
- Great Lakes Fisheries Strategic plan
- Lake Levels Reference study 1993
- Lake Ontario 1998 Plan
- Lake Superior Operation Criteria Study 2002
- IJC LOSLR Regulation Criteria Study (2000-06)
- IJC Upper Lakes Study (2006-11)
- Numerous wetlands, BMPs, regulations

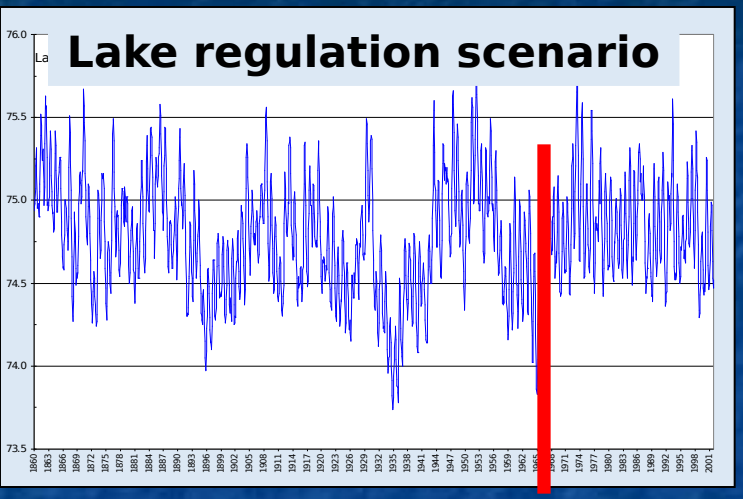


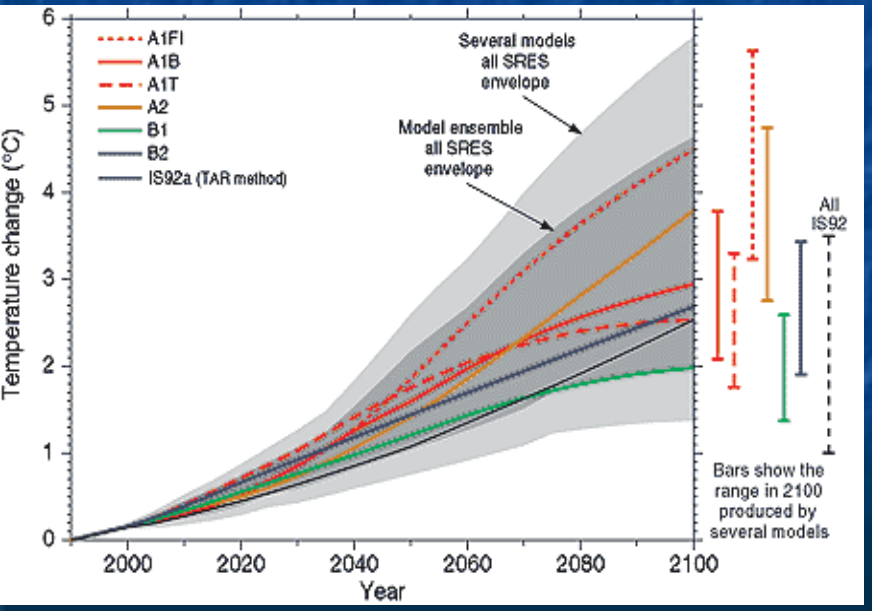
(Current Plan 1958D was not designed to handle the extreme low water of the 1960s or the high water of the 70s, 80s and 90s)

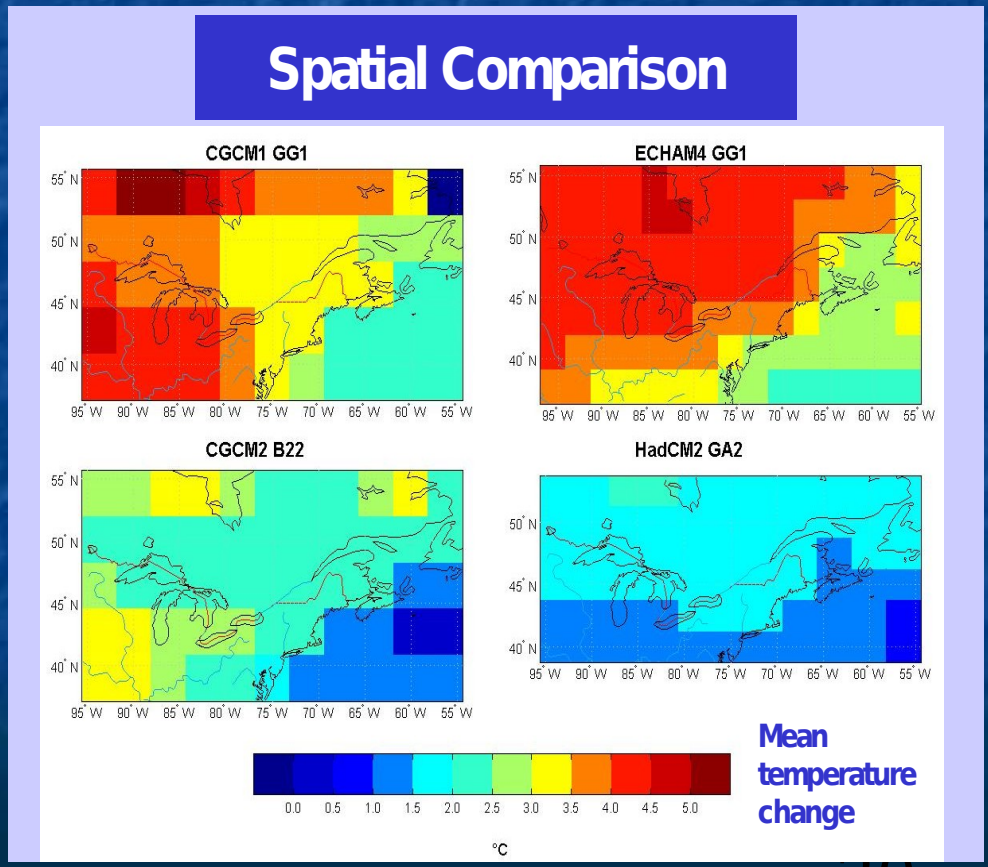
LOSLR Study Board Guidelines

- Contribute to **Ecological Integrity**
- **Maximize economic and ecological net benefits**
- No **disproportionate loss to any sector (Equity)**
- Flexible in recognition of **unusual or unexpected** conditions
- Adaptable to **climate change** and **climate variability** (AM Plan for key uncertainties)
- **Adapt** to future advances in knowledge, science and technology (Adaptive Management Plan)
- Decision-making will be **transparent and representative**

Hydrologic Scenarios Including Climate Change







International Lake Ontario – St. Lawrence River Study

Candidate Plans:

- A+: Balanced Economics
- B+: Balanced Environmental
- D+: Blended Benefits (selected plan)

Natural Flow Plan

- E: Natural Flow

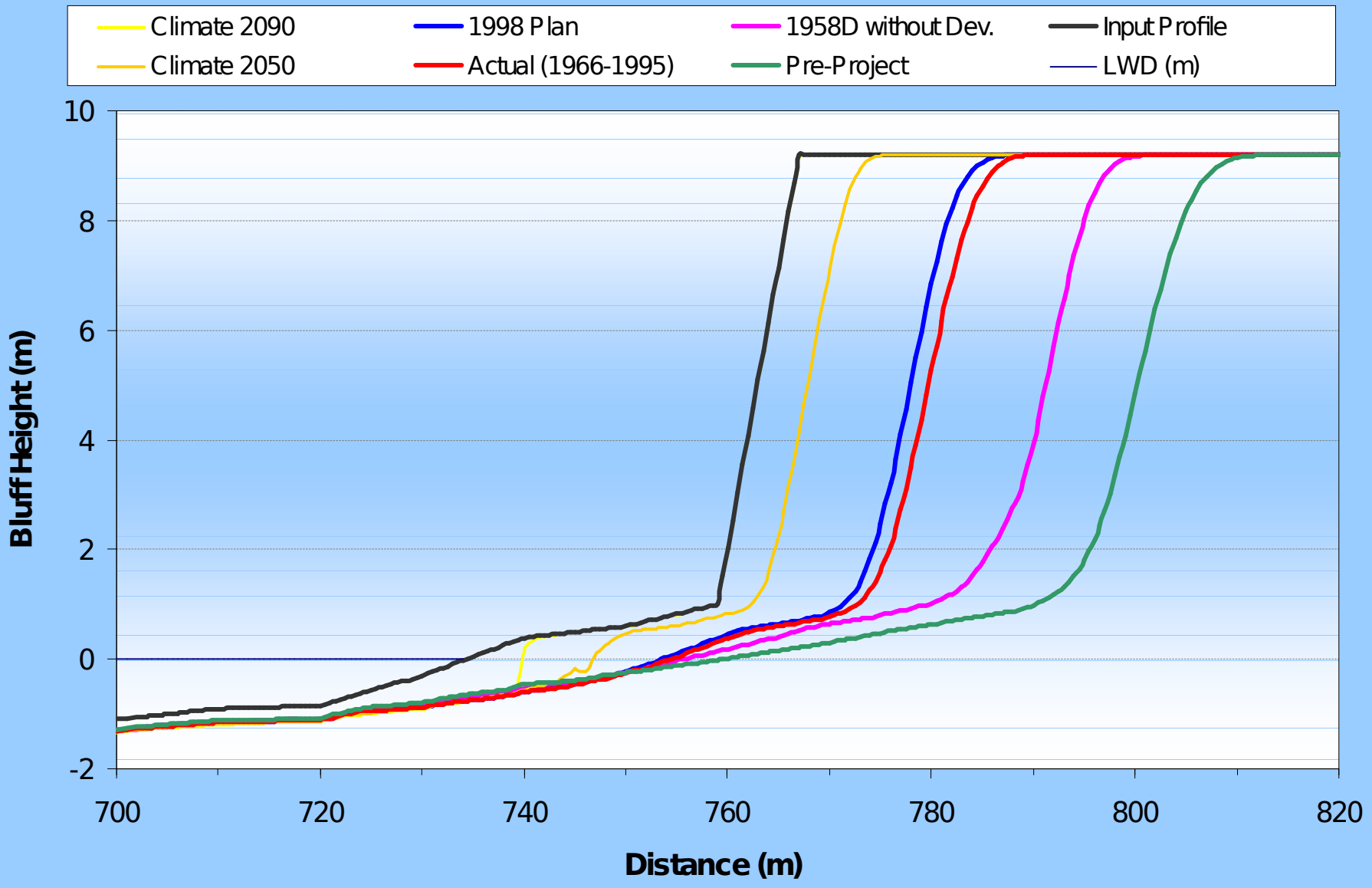
Interest Specific:

- Ontario Riparian Plan
- Recreational Boating Plan

Reference Plans:

- Plan 1998
- Plan 1958DD
- Plan 1958D

Bluff Recession for Different Plans (same wave climate)



Net Economic/Ecologic Benefits of Alternative Plans

Avg. annual net benefits ($US million)	Plan 58DD	Plan A	Plan B	Plan D	Plan E
Net Benefits	**0.00**	**7.52**	**6.48**	**6.52**	**-12.30**
Shoreline Damages	0.00	**-0.62**	**-1.11**	0.32	**-25.96**
Navigation	0.00	0.41	2.20	2.31	4.13
Recreation Boating	0.00	4.23	**-0.58**	2.04	**-4.64**
Hydroelectric	0.00	3.50	5.97	1.82	14.16
Municipal Water	0.00	0.00	0.00	0.00	0.00
Environmental Index	**1.00**	**1.06**	**1.35**	**1.17**	**4.04**
Wetlands Index	**1.00**	**1.02**	**1.44**	**1.25**	**1.56**

Economic Robustness of Plans w.r.t Climate Change Scenarios

Avg. ann. net benefits ($US million)	Plan 1958D	Plan A	Plan B	Plan D	Plan E
Plan 1958DD	0	7.52	6.48	6.52	-12.30
C1- Hot/Dry	-115.65	34.89	-1.42	20.09	-4.91
C2 - Warm/Dry	-49.52	9.85	4.89	5.25	-34.03
C3 - Hot/Wet	-81.69	21.53	2.61	17.77	-2.46
C4 - Warm/Wet	13.98	8.33	11.78	9.65	-21.38

Stochastic Scenarios: 4 representative centuries based on 50,000yrs

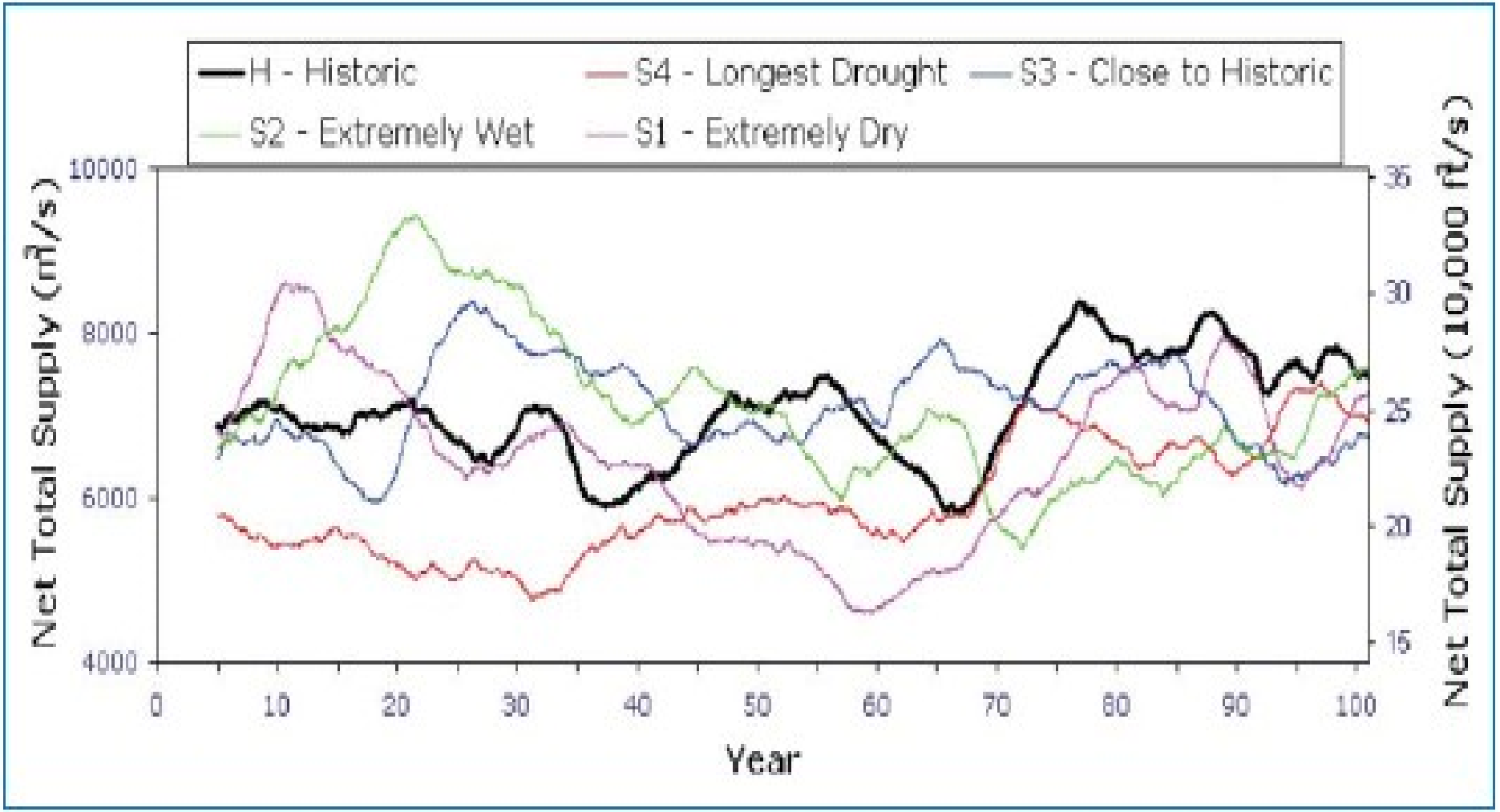
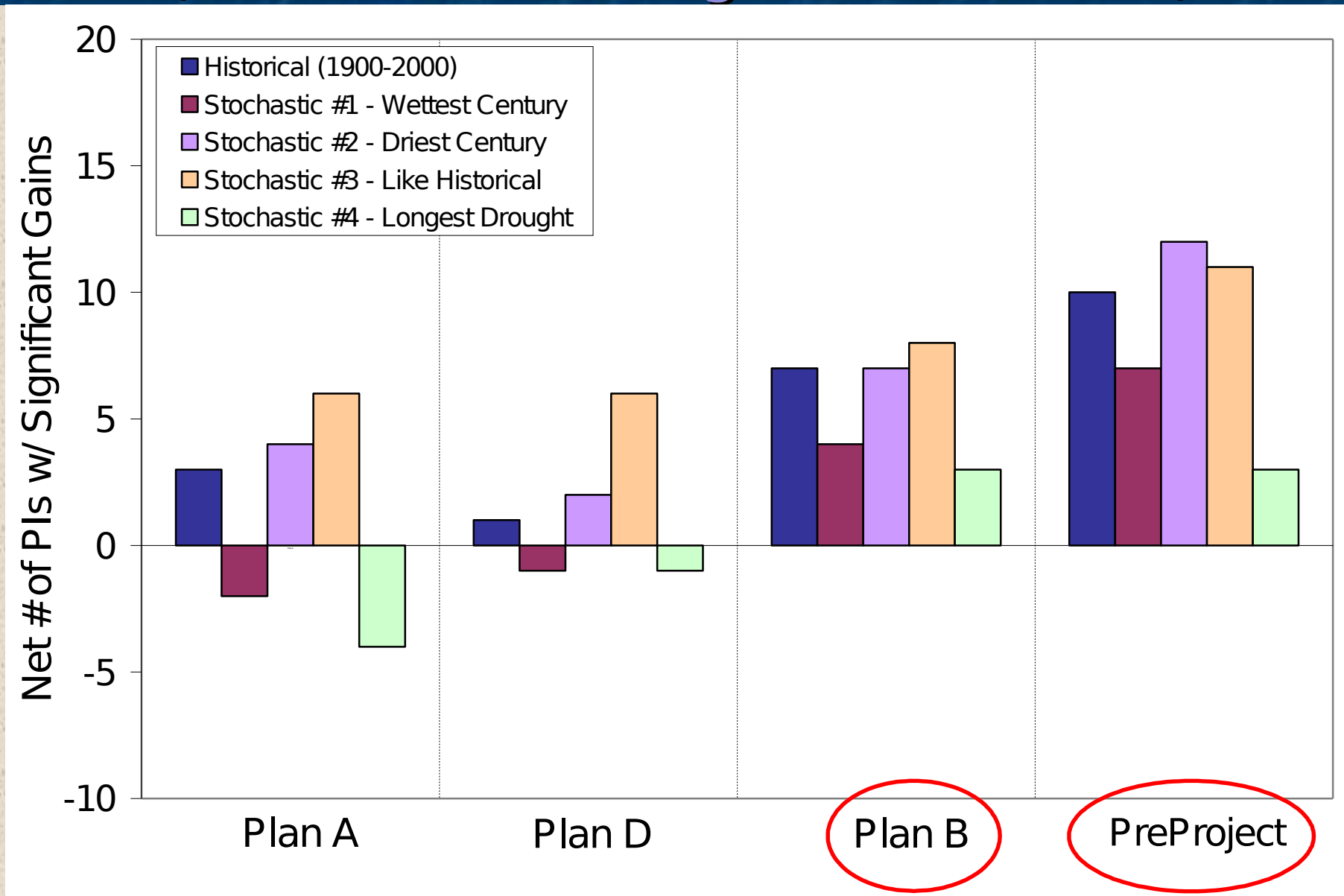


Figure 42: Five-year moving average of the net total supply (NTS) for the four stochastic centuries (S1-S4) and the historical

Stochastic Scenarios:

(# Ecol PI's with gains or losses)



Summary/Conclusions

- Water resources management has been and is inherently a **self-adapting enterprise** – hydrology & hydraulics, planning, design & operations, technology is constantly adjusting.
- Large events (e.g. Katrina, Miss R. Flood) force innovations -**rate of adaptation** is the issue.
- **Continuous adjustment** (autonomous adaptation) to climate variability, changes in water use patterns, values and demands (e.g. US water use has declined since 1975)
- **IWRM/CZM** is a keystone of, and prerequisite for purposeful strategic **“no regrets”** approach
- **Tighter regulations** (e.g.TMDL’s) impose efficiencies and technological adaptation, Best Mgmt Practice’s
- **Technological advances**, esp. in energy, agricul. & biotech will provide ‘buffering’ in future – society can/will adapt

Summary (Cont'd)

- Need to *move beyond* IPCC broad impact analysis to developing specific **evaluation frameworks** which couple economics with hydrology to deal explicitly with R&U of climate change and variability
- Focus on **variability** – informed by climate change
- Focus on **adaptation**: planning & evaluating alternative approaches, models, tools, technologies
- Focus on **applied R&D** for analytical tools for hydrology, hydrologic engineering under non-stationary climate
- **Standardize** use and tools of R&U analysis in planning & design of water infrastructure
- Emphasis on advances in short-term **flood forecasting**, and meso-scale GCM modeling will result in more reliable water management